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Q1. Activation energy is the minimum energy that is required for a successful reaction between colliding molecules.

Q2. Activation energy is NOT related to, nor can it be predicted from, the enthalpy change for a reaction.

Q3. The spark provides the activation energy for the combustion reaction.

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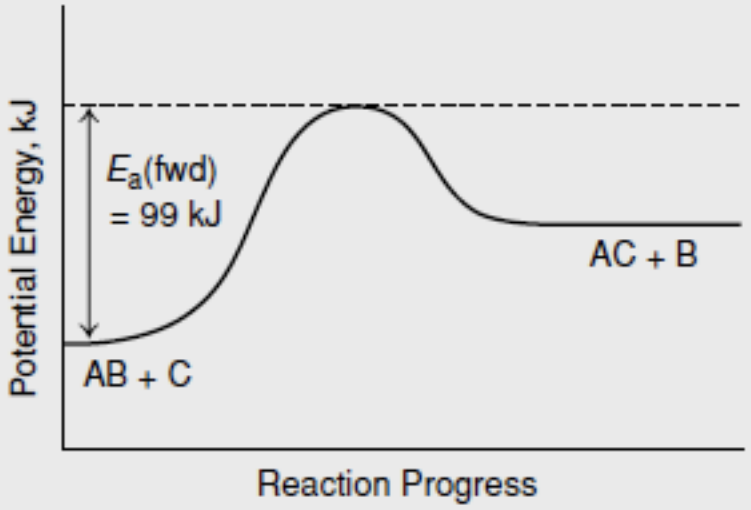
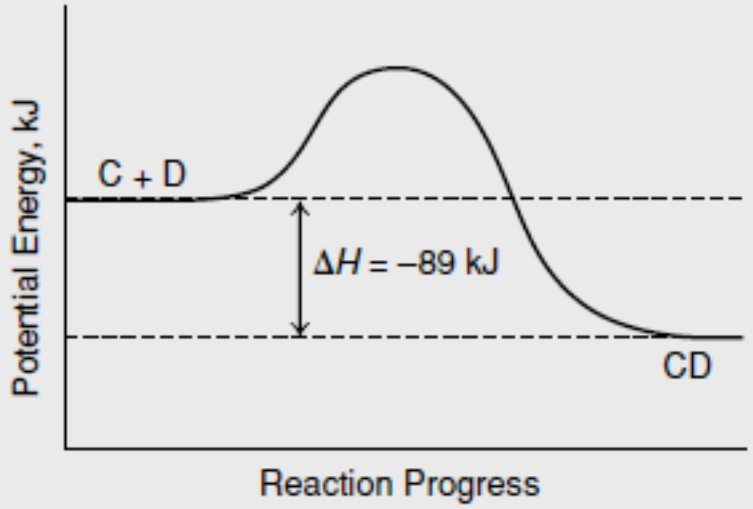
For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. The reaction is endothermic

2. $E_{a(fwd)} = 99$ kJ

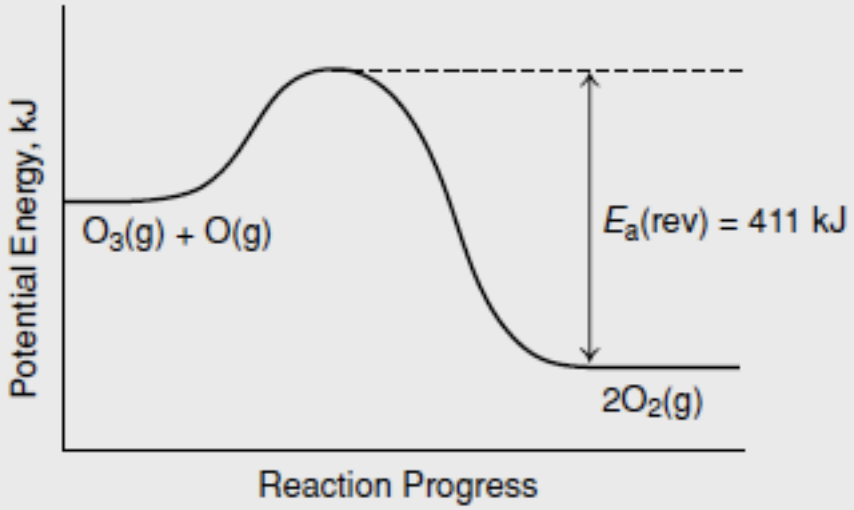


3. $\Delta H = -89$ kJ



4. $E_{a(fwd)} = 42$ kJ; $E_{a(rev)} = 67$ kJ; $\Delta H = -25$ kJ; exothermic reaction

5. $E_{a(rev)} = 411$ kJ



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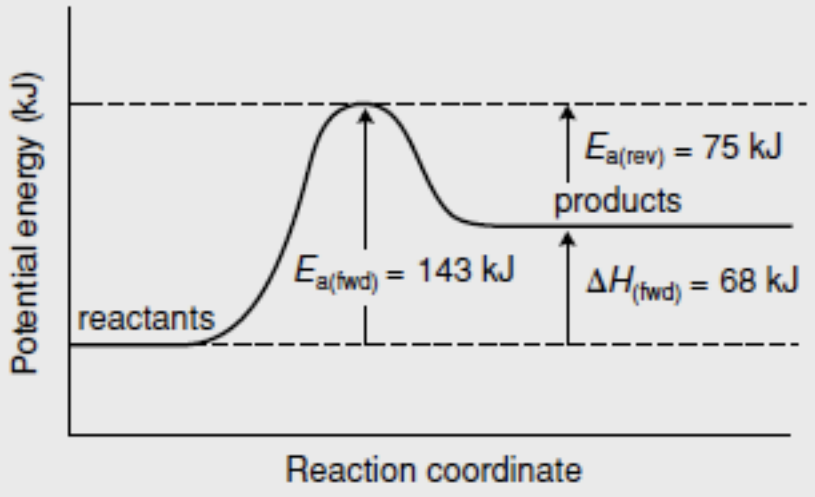
1. In order for a reaction to occur, molecules must collide with sufficient energy (activation energy) and correct collision geometry.

2. An increase in temperature increases the rate of a chemical reaction. If temperature is increased, the molecules will have a higher average kinetic energy so more collisions will have the activation energy to result in a reaction.
3. When molecules collide with sufficient energy, the kinetic energy of the collision is converted to potential energy as chemical bonds are broken and energy is stored in the partial bonds of the activated complex. As the partial bonds in the unstable activated complex form chemical bonds of the products, the potential energy is transformed into potential energy stored in the chemical bonds of the products. Remaining energy will be converted back into kinetic energy.
4. An activated complex is a highly unstable transition species that has partial bonds. It is neither product nor reactant, but something in-between.
5. A boulder sitting on the top of the mountain is unstable. It has gravitational potential energy and could roll off the mountain in either direction. An activated complex is similar in that it is unstable, in a high energy state, and could easily decompose to reform reactants, or form products.
6. **(a)** The reaction is endothermic in the forward direction.

(b)



The enthalpy change for the reaction can be calculated:

$$E_{a(rev)} = E_{a(fwd)} + |\Delta H^\circ|$$

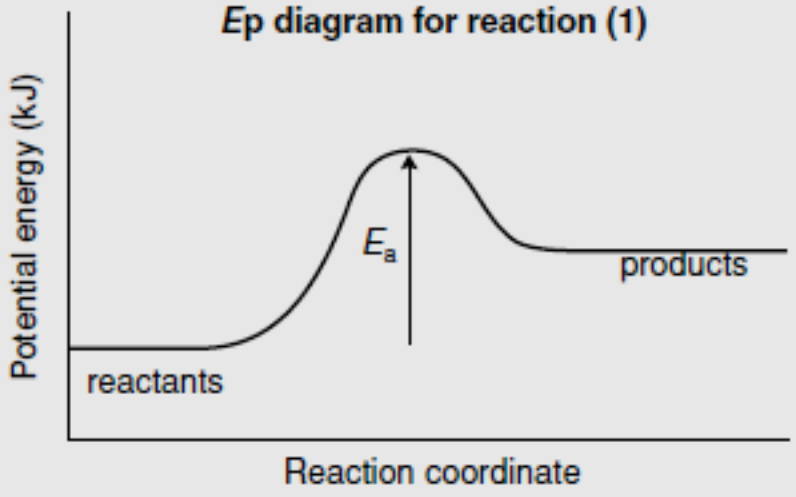
$$|\Delta H^\circ| = E_{a(rev)} - E_{a(fwd)}$$

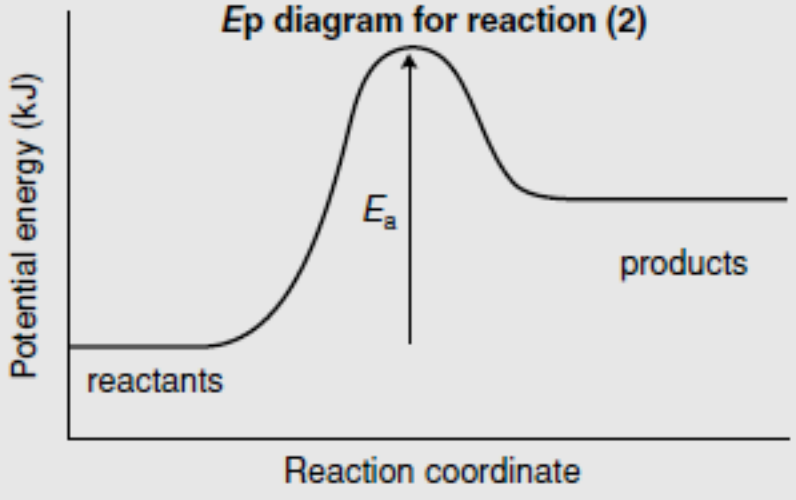
$$= 75 \text{ kJ} - 143 \text{ kJ}$$

$$= \pm 68 \text{ kJ}$$

The forward reaction is endothermic since its activation energy is larger than that of the reverse reaction, so the enthalpy change of the reaction in the forward direction is +68 kJ.

7. (a)





(b) Since reaction (1) has the smaller activation energy, it is likely to occur more quickly than reaction (2), assuming other factors such as temperature are similar in both reactions.

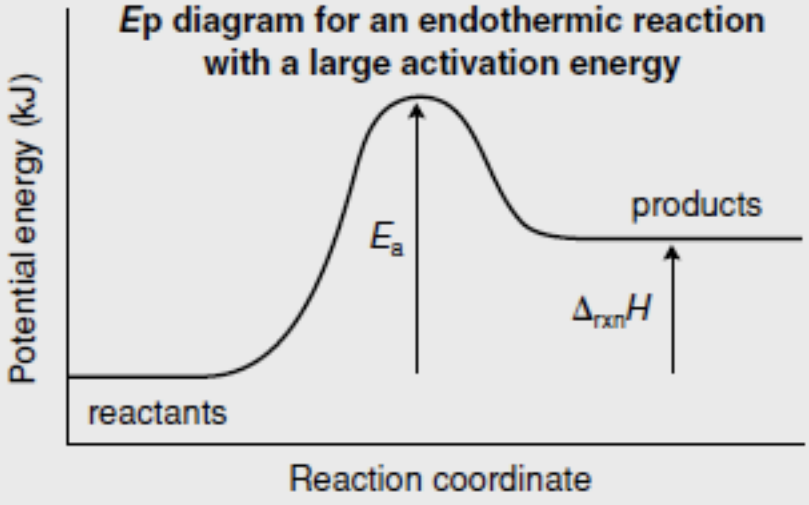
8. (a) I

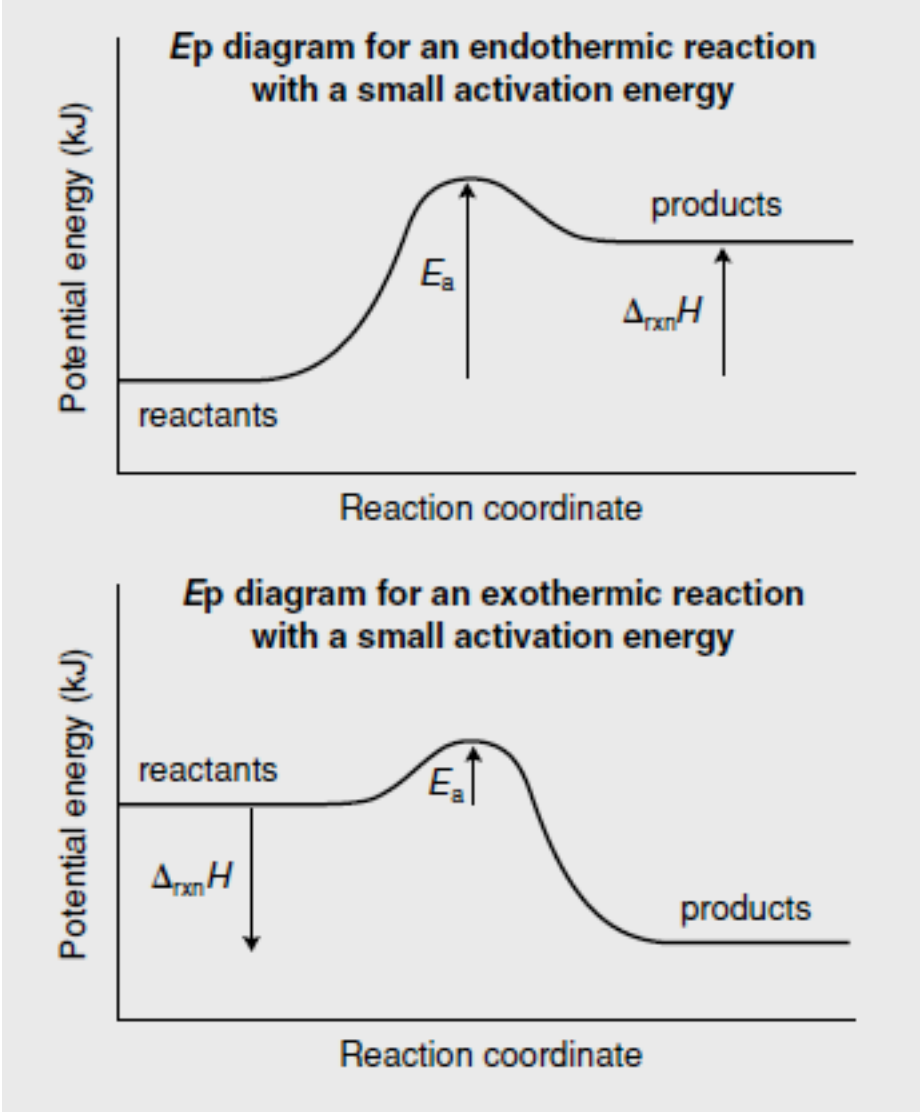
(b) IV

(c) III

(d) II

9. Activation energy is defined as the minimum energy that is required for a successful reaction between colliding molecules. It describes how much energy must be put in to get the reaction going, whereas enthalpy change is the amount of energy released or consumed when the reaction occurs. Activation energy and enthalpy change are completely independent of each other; that is, you cannot predict the activation energy of a reaction based on the enthalpy change. An exothermic reaction may have a very small or very large activation energy, as can an endothermic reaction. Regardless of whether a reaction is endothermic or exothermic, the larger the activation energy, the slower the reaction (assuming other factors such as reaction orientation are similar). Some examples of enthalpy change and activation energy are shown below:





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Q4. (a) $E_{a(fwd)}$ is lower with the addition of a catalyst.

(b) $E_{a(rev)}$ is lower with the addition of a catalyst.

(c) There is no change in ΔH with the addition of a catalyst.

(d) The speed of the forward reaction is increased.

(e) The speed of the reverse reaction is increased.

Q5. After the reaction is complete, the catalyst is restored to its pre-reaction state.

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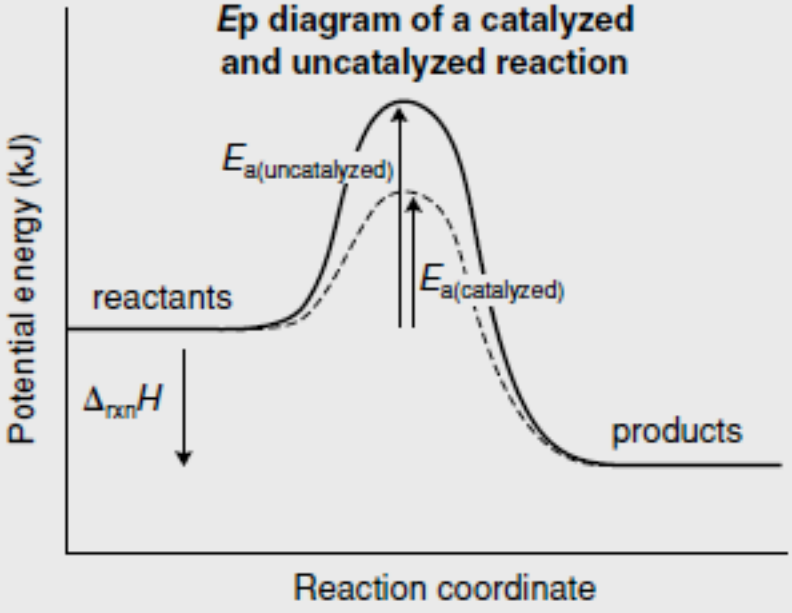
1. A catalyst has no effect on the total energy change from reactants to products because ΔH is only dependent on the potential energy difference between the reactants and products, not the pathway taken. As shown in the diagram below, the initial and final potential energy positions have not changed, so the enthalpy change for the reaction does not change.



2. Only a small amount of catalyst is necessary because a catalyst is regenerated when the reaction is complete and can be reused.

3. Enzymes and catalysts both speed up reactions and are regenerated at the completion of the reaction. Enzymes are extremely large molecules that only operate well at temperatures found in living systems, while catalysts are small molecules, often ions, that are not adversely affected by temperature.

4. **(a)** Pt(s), Pd(s), and Rh(s)
   (b) hydrocarbons, CO(g), and NOx(g) are removed; $CO_2(g)$, $H_2O(g)$, and $N_2(g)$ are the eventual products
5. The difference between a reactant in a reaction and a catalyst is that a reactant is consumed, whereas a catalyst is regenerated when the reaction is complete. If chlorine atoms were reactants, once they were consumed, they would no longer affect the ozone layer. Since they are catalysts, however, the chlorine atoms present can promote the destruction of the ozone layer forever (unless they can be removed in another way).
6. Students' answers will depend on the values they interpolate from the graph.
   (a) 575 kJ
   (b) 350 kJ
   (c) The catalyzed reaction is faster because the activation energy is lower.
   (d) 750 kJ
   (e) 525 kJ
   (f) –175 kJ
   (g) 175 kJ
   (h) According to Hess's Law, if you reverse a reaction, you change the sign of the ΔH. In this case, the reaction is reversed, so the ΔH changes from –175 kJ to 175 kJ.

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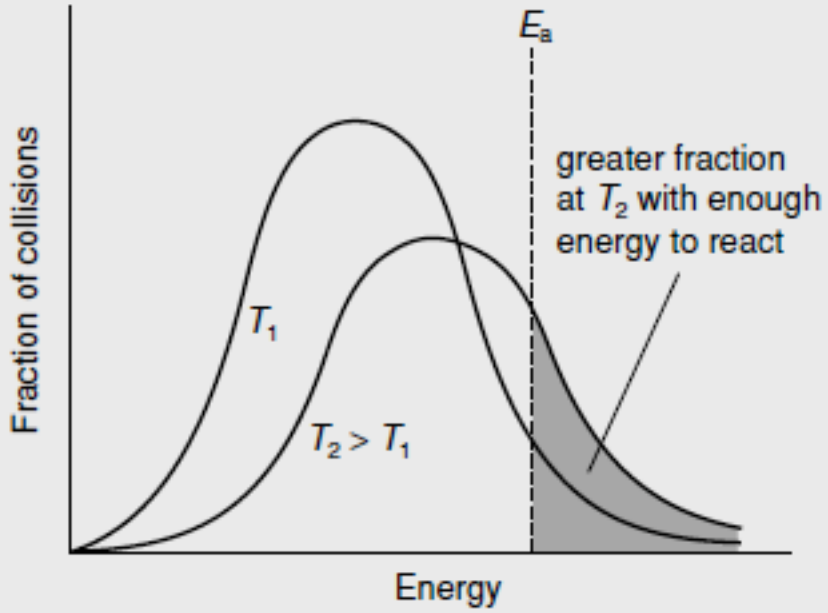
Answers to Understanding Concepts Questions

1. For a reaction to take place, molecules must collide with the correct orientation geometry and with sufficient (activation) energy.
2. A match will not light spontaneously. With the input of the kinetic energy of the strike, the chemicals reach the activation energy and the match will burn completely.

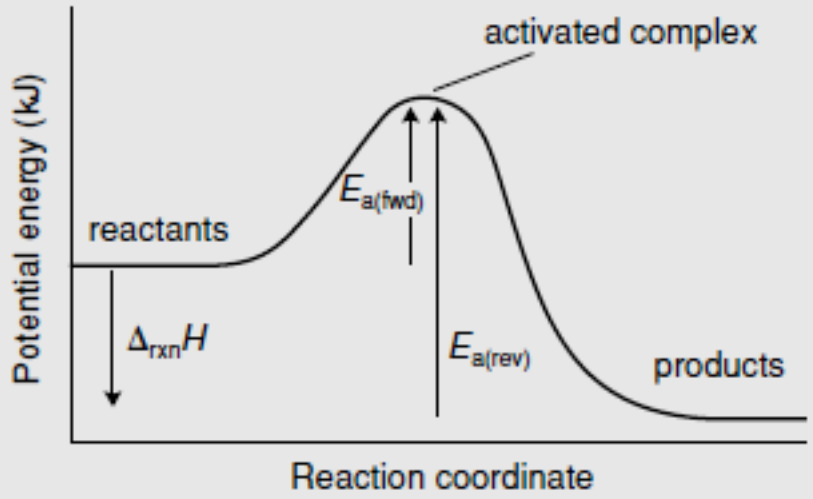
3. The activated complex is a highly unstable species that is neither product nor reactant. It is so unstable because it contains only partial bonds and has the most potential energy of all of the substances found in the reaction since it is at the highest peak of the reaction mechanism.

4. When temperature is increased, the fraction of collisions with sufficient energy to cause a reaction, represented by the area under the curve, increases. If there are more successful collisions, the rate of reaction increases.



5. The energy required to reach activation energy comes from the kinetic energy of the colliding molecules. As they collide, the kinetic energy is converted to potential energy.

6. The reaction is exothermic.



7. Catalysts are substances that increase the rate of a reaction by providing an alternate, lower activation energy pathway. If the energy barrier is lowered, a larger proportion of molecules will have sufficient energy when they collide to result in a reaction.

8. There is no effect on ΔH when a catalyst is added, therefore the enthalpy change of reaction remains the same. The catalyst changes the pathway of the reaction but as per Hess's law this has no effect on the enthalpy change of the reaction.

9. As molecules collide, their kinetic energy is converted to potential energy as bonds are broken. The species formed during this process is the activated complex, a highly unstable arrangement containing partial bonds. As the bonds reform to make more stable products, the potential energy is converted back into kinetic energy.

10. A catalyst, although part of a reaction, is not consumed or produced during the reaction and cannot be considered a reactant or product. Therefore, above the arrow, indicating that it is part of the reaction but not reactant or product is most appropriate.

11. (a) One example of an industrial catalyst is vanadium (V) oxide, $V_2O_5(s)$, used to speed up the second reaction of the contact process to produce sulfuric acid, $H_2SO_4(aq)$, commercially. Other industrial catalysts include Mo(VI) complexes which are used to make polyesters, nickel or platinum to hydrogenate vegetable oil and platinum, palladium and rhodium catalysts used in catalytic converters.

(b) One example of an enzyme is pepsin. It is produced by cells of the stomach and is used to digest protein in the stomach. Enzymes are used throughout the body to catalyze important reactions. Other enzymes include amylase, which digests starch, and carbonic anhydrase which catalyzes the conversion of carbon dioxide gas into carbonic acid.

(c) Both enzymes and catalysts increase the rate of reactions by providing an alternate lower-energy pathway. Catalysts are often small molecules or atoms that catalyze reactions between other relatively small molecules. These reactions may occur at very high temperatures. Enzymes must be able to facilitate effective collisions between very large molecules at relatively low temperatures. To do this, enzymes are complex, very large molecules that are folded in a specific way to create an active site on which the substrate molecules bind. Because the enzyme's activity is dependent on its shape, which in turn is dependent on conditions, its activity can be regulated through changes in pH, such as what happens with pepsin's activation in the stomach (low pH) and deactivation in the intestine (high pH).

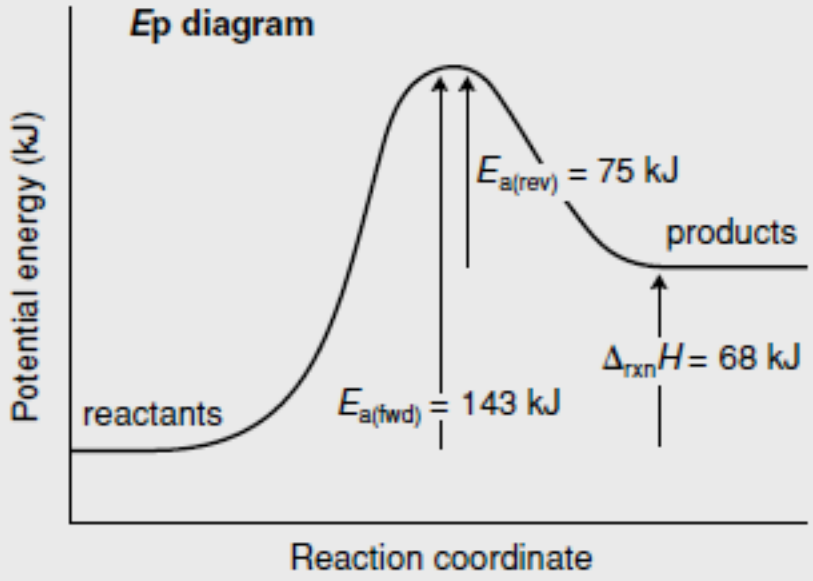
12. At high temperatures, the shape of an enzyme is altered which changes the shape of the active site. This change in shape will decrease or eliminate the enzyme activity, reducing the rate of the reaction.

Answers to Applying Concepts Questions

13. (a) The reaction is endothermic since the $E_{a(fwd)}$ is larger than the $E_{a(rev)}$.

$\Delta H = E_{a(fwd)} - E_{a(rev)} = 143\ kJ - 75\ kJ = 68\ kJ$; since this is positive we know the reaction is endothermic.

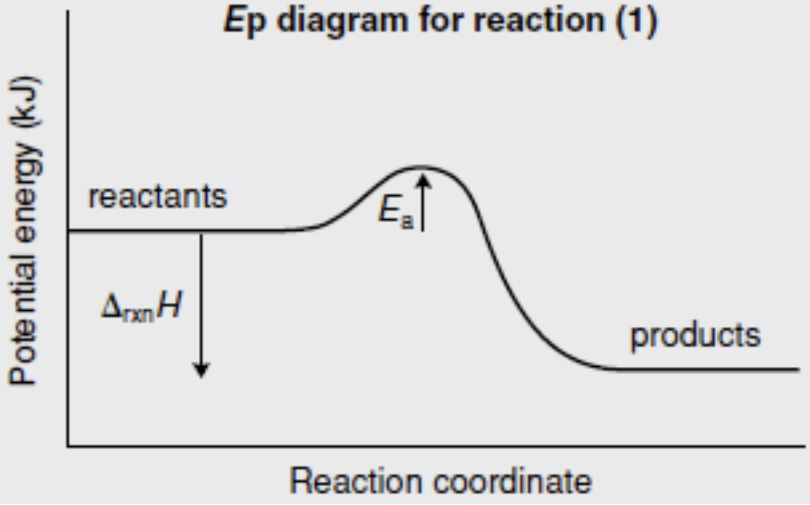
(b)

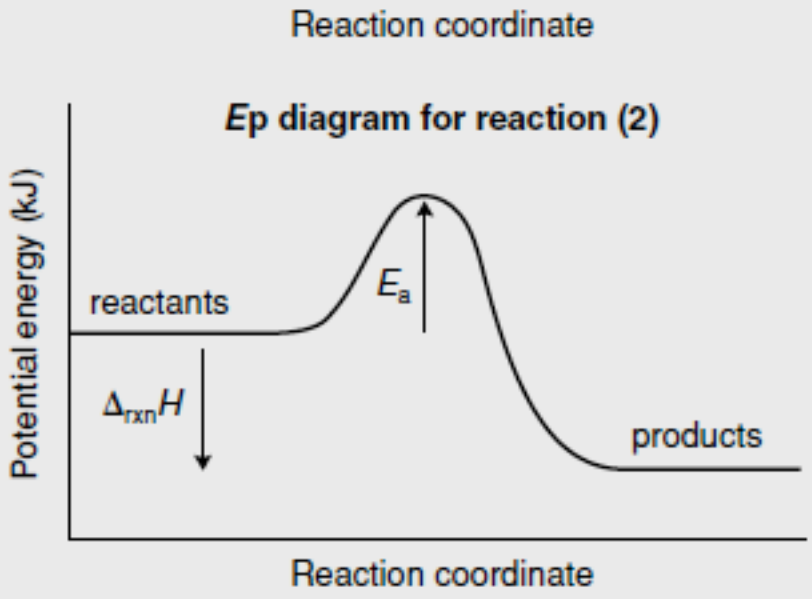


14. (a) $\Delta H = 50\ kJ$, $E_{a(fwd)} = 70\ kJ$, $E_{a(rev)} = 20\ kJ$

(b) $\Delta H = 50\ kJ$, $E_{a(fwd\text{-}cat)} = 58\ kJ$, $E_{a(rev\text{-}cat)} = 8\ kJ$

15. (a)





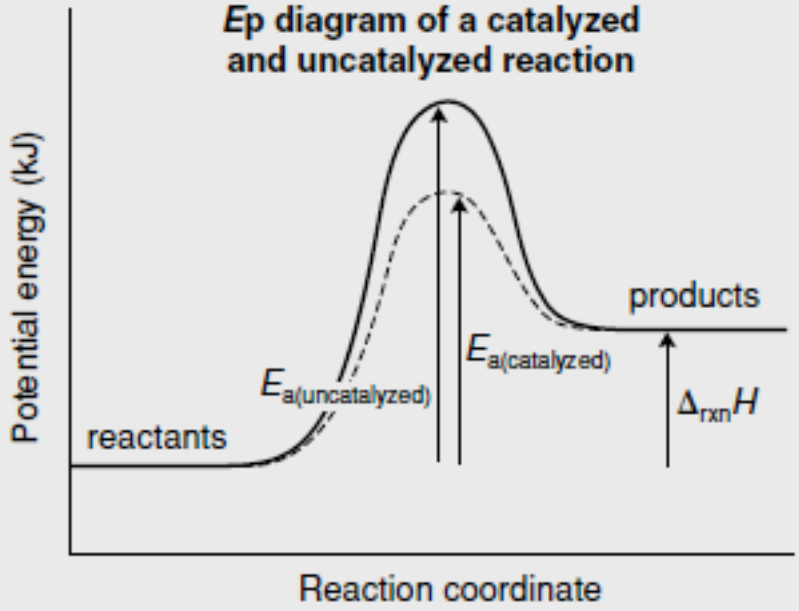
(b) Reaction (1) would have a faster rate given the same conditions, as its activation energy is lower, so more collisions will be effective.

16. The activated complex cannot be isolated because it is highly unstable, due to its partial bonds, and it is short-lived.

17. The activation energy required for the combustion of gasoline must be quite high, so the reaction will not occur spontaneously. The spark required for ignition provides the necessary activation energy.

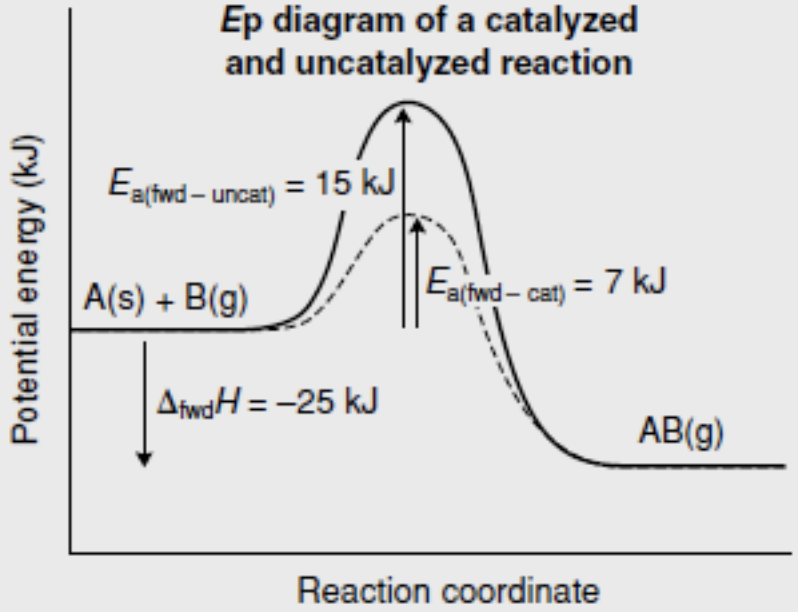
18. (a) A catalyst has no effect on the total energy change because it only affects the path taken from reactants to products. As the potential energy diagram in (b) illustrates, the initial and final potential energy positions of the reactants and products do not change with the addition of a catalyst.

(b)


Ep diagram of a catalyzed and uncatalyzed reaction
Potential energy (kJ)
products
$E_{a(catalyzed)}$
$E_{a(uncatalyzed)}$
$\Delta_{rxn}H$
reactants
Reaction coordinate

19. (a) 7 kJ

(b)


Ep diagram of a catalyzed and uncatalyzed reaction
Potential energy (kJ)
$E_{a(fwd-uncat)}$ = 15 kJ
$E_{a(fwd-cat)}$ = 7 kJ
A(s) + B(g)
$\Delta_{fwd}H$ = –25 kJ
AB(g)
Reaction coordinate

20. (a) Measure the volume of gas ($H_2(g)$) produced over time.

(b) Record the time until the violet colour disappears.

(c) Measure the change in gas pressure over time.

(d) Measure the decrease in gas pressure over time, or the change in mass of the precipitate after a specific amount of time.

21. Since inhibitors decrease the rate of reaction, they may act to increase the activation energy.

22. (a) The spark is providing activation energy; it is not a catalyst as it is not a substance.

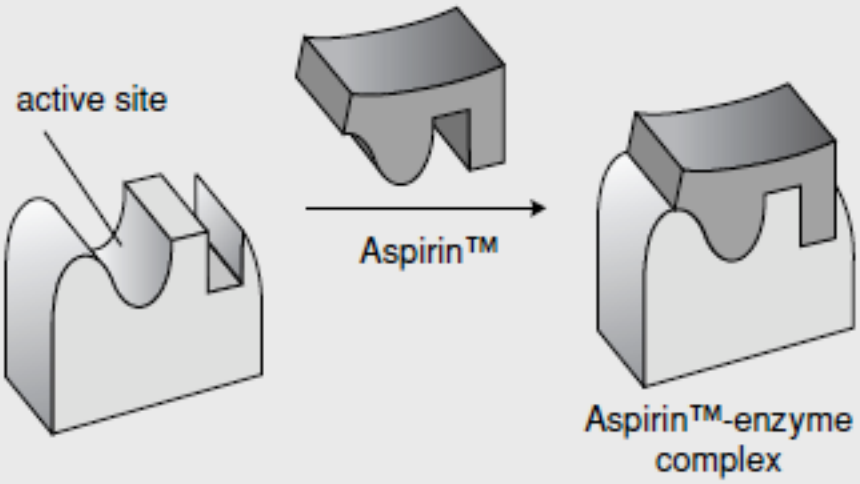
(b) The metal is likely acting as a catalyst since it is required for the reaction to occur. Although it is not mentioned, it appears that the metal is not consumed in the reaction, which is also true for catalysts.

Answers to Making Connections Questions

23. Lead in gasoline and in paint can cause lead poisoning. Lead interferes with the enzyme delta-aminolevulinic acid dehydratase that is important in the synthesis of the heme complex, part of hemoglobin, which is responsible for carrying oxygen in the blood. Although leaded gasoline has been banned in North America for more than 20 years, it is still being sold in third world countries, Eastern Europe and elsewhere in the world. North America and its citizens were quick to spend money on new technology to bring in unleaded gasoline and vehicles equipped with catalytic converters; however, in areas of the world where money and technology are more difficult to come by, leaded gasoline will not be phased out as quickly.

24. The reaction catalyzed in the catalytic converter is only effective at temperatures above 288 °C. To solve this problem, the catalytic converter could be preheated before the car is started using a block heater.

25. Student answers should note that Aspirin™ inhibits the enzyme that produces prostaglandins, the messengers that trigger inflammation in the body. Researchers have shown that Aspirin™ forms a strong bond to the enzyme, changing its shape and permanently blocking that molecule. The diagram below illustrates how Aspirin™ binds to the active site of the enzyme. Unlike the substrate, the Aspirin™ forms a strong bond with the enzyme, preventing the enzyme from bonding with a substrate molecule.



26. Student answers should note that detergents are products that contain enzymes and are designed to remove dirt.

27. (a) Ethanol is toxic. During binge drinking, ethanol will accumulate in the body faster than it can be broken down by alcohol dehydrogenase. The accumulation of ethanol impairs heart function and breathing and can lead to death.

(b) Ethanol will compete with methanol for the active site on alcohol dehydrogenase enzymes, acting as a competitive inhibitor. If the methanol metabolism is slowed enough that the formaldehyde levels do not accumulate in the body, blindness and death can be avoided.

28. (a) If lead forms strong bonds with an enzyme's active site, the enzyme cannot bind to the substrate and catalyze the reaction necessary for life, leading to sickness.

(b) The lead must also bind to a site on either egg white or milk. The stomach must be pumped to remove the lead/egg white or lead/milk compound from the digestive system before the milk and egg white are digested and the lead is absorbed into the bloodstream.

29. Since temperature affects the rate of all chemical reactions, when cold-blooded animals are not able to increase their body temperatures, all of their bodily processes, including cellular respiration, which produces the energy required to move, would be slowed.